APPENDIX

Figure 4 shows the block diagram of the FEC for a DOCSIS 1.2 system using BICM code, where the blocks with the gray background are the blocks to be added to the FEC.

The following document lists the additions to the draft DOCSIS 1.2 for adding a BICM mode.

Section 4.2.2. Signal Processing Requirements

Figure 4-4 should be replaced with Figure 5. The blocks that are effected by adding the BICM are drawn with a gray background.

Section 4.2.10 Trellis Coded Modulation

Change the name of the section to "Coded Modulation", and replace the first sentence with: "The upstream modulator MUST support 8-state TCM encoding and *Bit-Interleaved Coded Modulation (BICM)* for 2-dimensional modulation symbols."

Add the following subsections to section 4.2.10:

4.2.10.3 BICMs Bit Encoder

Figure 6 shows the BICM bit encoder. It consists of a rate ½ convolution encoder followed by a puncturing unit. Such an encoder is widely use in the digital communications industry.

The constraint length of convolution encoder is 7 bits, and its generator polynomials are 133 octal and 177 octal. The outputs of the convolution encoders are:

$x_n = XOR(b_n , b_{n-1} , b_{n-2} , b_{n-3} , b_{n-6})$ $y_n = XOR(b_n , b_{n-2} , b_{n-3}, b_{n-5} , b_{n-6})$

where b_n is the n-th input bit to the decoder. The initial state of the convolution-encoder must be the zero state. After encoding of all information bits in an upstream packet, six additional zero tail information bits are added.

The puncturing pattern of the puncturing unit is:

Code Rate	Puncturing pattern	Output
½	x: 1 y: 1	$x_n\ y_n$ (n=0,1,2,...)
2/3	x: 1 0 y: 1 1	$x_n\ y_n\ y_{n+1}$ (n=0,2,4,...)
¾	x: 1 0 1 y: 1 1 0	$x_n\ y_n\ y_{n+1}\ x_{n+2}$ (n=0,3,6,...)
5/6	x: 1 0 1 0 1 y: 1 1 0 1 0	$x_n\ y_n\ y_{n+1}\ x_{n+2}\ y_{n+3}\ x_{n+4}$ (n=0,5,10,...)

The puncturing mode and the constellation to be used for m=1,2,..6 information bits per symbol are:

m [bits/symbol]	1	2	3	4	5	6
Constellation	QPSK	16QAM	16QAM	64QAM	64QAM	256QAM
Puncture mode	1/2	1/2	¾	2/3	5/6	3/4

4.2.10.4. Symbol Mapping for BICM

When using BICM, the CM shall use the QPSK, 16-QAM and 64-QAM Gray coded constellations defined in 4.2.9.2. The symbol mapper input bits will be read serially from the bit interleaver (section 4.2.11.2). In the 256QAM mode of BICM, the CM will use conventional Gray code constellations. The input bit definition (MSB-LSB) will be $I_3\ Q_3\ I_2\ Q_2\ I_1\ Q_1\ I_0\ Q_0$. The gray mapping of the real and the image and real parts of the symbol is:

$B_3\ B_2\ B_1\ B_0$	0010	0011	0001	0000	0100	0101	0111	0110
Value	-15	-13	-11	-9	-7	-5	-3	-1
$B_3\ B_2\ B_1\ B_0$	1110	1111	1101	1100	1000	1001	1011	1010
Value	1	3	5	7	9	11	13	15

The following sub-section should be added to section 4.2.11.

4.2.11.2 BICM Bit Interleaver

BICM Bit Interleaver bits shall be interleaved after inner coding in order to add time diversity to the signal, and thus to improve robustness to impulse and burst noise. Due to the bit interleaving operation, a noise burst that causes a sequence of multiple symbol errors appears

after de-interleaving as several events of a single channel bit error, which are more easily recovered by the decoder.

Similarly to the symbol interleaving case, the two parameters that define the structure of the bit interleaver are the interleaver depth (I_t), and group length (N_t), measured in units of bits. The bits are written serially to the interleaver-matrix line by line and read serially column by column. When the number of coded bits in the packet is not an integer multiple of N_t bits, the last group of the packet is made shorter than a full group (N_t').

The total block size allocated for the interleaver shall be the same as the size allocated for the TCM symbol interleaver, which is currently 7168 bits. The group length N_t shall be programmable in the range 1,..255, and the interleaver depth shall be programmable in the range 0..ceil(7168/N_t), where as in the case of symbol interleaving I_t=0 denotes dynamically configured I_t value, and where N_t=1 is the case of no bit interleaving.

Figure 7 shows an example of the bit interleaving process, in the case of a packet of 16 coded bits, N_t=5, and 16QAM modulation.

In this example, the first symbol will consist of the bits z_1, z_6, z_{11}, z_{16}, the second symbol will consist of z_2, z_7, z_{12}, z_3; the third symbol will consist of z_8, z_{13} , z_4, z_9; and the last symbol consists of the bits z_{14}, z_5 , z_{10}, z_{15}.

Similarly to the case of symbol interleaving, when I_t=0 and the number interleaved bits N_p is not larger than 7168 bits, I_t is dynamically configured at the CM according to the formula

$$I_t = ceil(N_p/N_t)$$

When N_p is larger than 7168 bits, the packet should be interleaved in multiple segments using the algorithm used for symbol interleaving for the case of more than 1024 symbols per packet.

Preamble Prepend (section 4.2.12)

Add the following subsection:

4.2.12.1 Preamble Insertion in BICM mode:

When BICM is used, the preamble symbols can be added in two modes: either before the data symbols, or they may be interleaved within the data symbols. In the later case the preamble

symbols are inserted every MIN{ 8, *ceil*($N_{MESSAGE}/N_{PREAMBLE}$) } symbols starting from the first symbol, where $N_{MESSAGE}$ is the number of encoded data symbols in the burst, and $N_{PREAMBLE}$ is the number of preamble symbols. For example, when $N_{MESSAGE}$=13 and $N_{PREAMBLE}$=4, the burst will be P_0 D_0 D_1 D_2 D_3 P_1 D_4 D_5 D_6 D_7 P_2 D_8 D_9 D_{10} D_{11} P_3 D_{12}, where P_n and D_n denote the preamble and the data symbols respectively.

Burst Profile Attribute (section 4.2.15 - table 4-6.)

- change "TCM Coding On/Off = On/Off" with "*Inner Coding Scheme = Off/TCM/BICM*
- N_t can be configured to 1,..255 (at least in the case of BICM).
- Notation changes:
  1. change "Modulation=QPSK,8QAM,...128QAM" with "*Information bits per symbol (m) = 1 to 6*"
  2. Change "TCM Interleave" with "*Inner* Interleave".
  3. regarding preamble insertion position, change "Before/After TCM Interleaver" with "Interleaved/Non-interleaved".